Docket No. WG-97-10

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Washington, D.C. 20231

NEW PATENT APPLICATION TRANSMITTAL LETTER

Sir:

Transmitted herewith for filing is the patent application of **FREDERICK J. BARR and JOSEF PAFFENHOLZ** for **SEISMIC DATA ACQUISITION AND PROCESSING USING NON-LINEAR DISTORTION IN A GROUNDFORCE SIGNAL.**

Enclosed are:

[X] A specification consisting of a title page, a 20 page disclosure, 7 pages of claims, and a 1 page abstract of the disclosure.
[X] One set of INFORMAL drawings consisting of 2 sheets.
[X] An assignment of the invention to Western Atlas International, Inc.
[X] A combined Power of Attorney and Declaration executed by all of the Inventors.
[ ] A Power of Attorney executed by the Inventor(s)/Assignee.
[ ] An Information Disclosure Statement (with PTO form 1449).
[ ] Declaration executed by the Inventor(s).

CLAIMS AS FILED				OTHER THAN SMALL ENTITY		
Total Claims	33 - 20 =	13	X	$ 22.00	=	$ 286.00
Independent Claims	4 - 3 =	1	X	$ 82.00	=	$ 82.00
Basic Fee					=	$ 790.00
TOTAL FILING FEE					=	$ 1158.00

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Respectfully submitted,

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Date: November 14, 1997

E. Eugene Thigpen, Registration No. 27,400

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Signature: E. EUGENE THIGPEN
Date of Signature: November 14, 1997

November 14, 1997

WG-97-10

APPLICATION FOR UNITED STATES PATENT

FOR

SEISMIC DATA ACQUISITION AND PROCESSING USING NON-LINEAR DISTORTION IN A GROUNDFORCE SIGNAL

INVENTORS:

FREDERICK J. BARR
JOSEF PAFFENHOLZ

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SEISMIC DATA ACQUISITION AND PROCESSING USING NON-LINEAR DISTORTION IN A GROUNDFORCE SIGNAL

BACKGROUND OF THE INVENTION

Field Of The Invention

The present invention is directed to seismic data processing, to pre-processing seismic data in which data generated by a vibrating source is received and prepared for data processing, and to methods for refining seismic field data.

Description of Related Art

Certain prior art seismic data acquisition and processing systems use a vibratory source to apply a force to the ground and measure subsequent motion caused by the application of this force at various receiver locations. By controlling the duration and frequency of the force a broad band signal with sufficient energy is achieved. By using the receiver motions and assumed force application a seismogram is constructed (typically by correlation with an estimate of the applied force) from which properties of the impedance function of the earth can be calculated. In certain systems data that is generated by a vibratory source is correlated with a reference sweep. A reference sweep signal is an ideal signal which the vibrator is told to put into the ground, which is often quite different from the actual signal which is generated. The typical estimate for the applied force is the mass weighted sum of the acceleration of the baseplate used in the vibrating source and the acceleration of the reaction mass used in the vibrator structure, called the groundforce.

One prior art method commonly used in the seismic industry for compressing seismic field data is that of crosscorrelating each seismic trace with a pilot sweep used to drive vibrators. The pilot sweep is typically a sinusoidal signal whose instantaneous

frequency increases or decreases with time in a preprogrammed manner. Electronic systems are built into field recording systems to perform this mathematical computation prior to writing the resulting, compressed traces to magnetic tape. A shortcoming of this method is that it ignores distortions in the actual output of a vibrator unit caused by non-linearities in both the electro-hydraulic system and the elastic properties of the topsoil against which the vibrator's baseplate applies its force signal. This soil non-linearity can be expected to be different for each location where the vibrator inputs its force signal. These system non-linearities cause the actual force output signal from the vibrators to contain the fundamental pilot sweep signal as well as harmonics and sub-harmonics of that sweep signal. Hence, each subsurface reflection is represented in the uncompressed data by this distorted sweep signal. When the uncompressed data are crosscorrelated with the pilot sweep, the fundamental pilot sweep portion is compressed into the desired zero-phase Klauder wavelet. However the harmonics and sub-harmonics manifest themselves as coherent noise.

U.S. Patent 5,550,786 discloses a method for processing data from a system using an accelerometer on a vibrator's baseplate and an accelerometer on a reaction mass used with the vibrator structure. A signal which is minimum phase related to the actual force generated into the surface of the earth is measured and taken from a vibrator source directly, i.e., an actual signal [not a measured groundforce signal, but an accelerometer (baseplate or reaction mass) signal] is used in the process instead of a theoretical signal. A method is provided for recording and pre-processing high resolution vibratory source data for both land and marine environments which includes measuring the motion or motions of the vibrator which are related to the actual vibrator applied force by a transfer function of a minimum phase, causal, linear system. This system relates the actual vibrator output with the measured vibrator motion or motions. A ratio is determined by

dividing the vibratory seismic data by the measured motion or motions of the vibrator to remove the unknown applied force leaving the earth reflectivity times a time derivative divided by a minimum phase function. Minimum phase deconvolution is performed to remove the time derivative divided by the transfer function of minimum phase. The method may also include the steps of receiver ensemble deconvolution, statics correction, F-K (frequency-wave number domain) filtering for linear noise, zero phase spiking deconvolution and model dephasing. In this method, a signal directly related to the actual signal that the vibrator is sending into the ground is used in pre-processing. The vibrator motion or motions are measured to provide a signal that is used to process the data. Thus, the data is not correlated with a theoretical sweep signal, but is divided by a minimum phase relative of the actual transmitted signal in the frequency domain, which removes the actual transmitted signal from the determination. When solving for the earth reflectivity, data is basically divided by the vibrator groundforce multiplied by a transfer function of minimum phase, removing the vibrator force from the data. This leaves the earth reflectivity multiplied by a time derivative divided by a minimum phase transfer function, which ratio is then removed by minimum phase deconvolution.

Each recorded trace is inverted as follows:

$$C(\omega) = T(\omega)/A(\omega)$$

where:

$C(\omega)$ = Fourier transform of the inverted trace

$T(\omega)$ = Fourier transform of the recorded seismic trace

$A(\omega)$ = Fourier transform of the baseplate or reaction mass accelerometer signal

The method applies a minimum phase bandpass filter and then relies upon statistical, spiking deconvolution of the resulting trace to obtain a minimum phase wavelet that represents each subsurface reflector in the trace. This method requires the application and

proper function of spiking deconvolution to achieve correct results. The presence of random noise (including noise related to non-linearities in the vibrator electrohydraulic system and baseplate/soil coupling) in the inverted traces can compromise the effectiveness of the derived spiking deconvolution operator.

In another prior art method Li has attempted to eliminate ghost noise (non-linear noise related to electrohydraulic system and/or baseplate coupling) in uncorrelated seismic (e.g. vibroseis) data using an inversion approach similar to that of U.S. Patent 5,550,786, except that computed groundforce is used. In this system a recorded groundforce signal, known to be a better correlator for a seismogram than a pilot sweep itself, is used to deconvolve the vibrogram. In such a way a ghost sweep, produced by severe harmonic distortions in the groundforce signal both at negative and positive correlation times (if such a signal is used as the correlator), is eliminated automatically. This method eliminates the correlation noise caused by both the upsweep or by the downsweep pilot signal. Synthetic and real data are used to demonstrate the application of the inversion procedure and the results differ from those achieved with the correlation procedure. After a first inversion, a second filter (e.g. an inverse Q-filter) may be applied to eliminate stratigraphic effects.

Li noted that harmonic distortion occurs in most vibrator operations on land because nonlinear effects cause an actual baseplate signal to differ from the signal of the pilot sweep of the encoder. In choosing which signal to use to correlate a vibroseis trace, Li refers to the work of Seriff and Kim (1970) which provided a fundamental study according to which the harmonic distortion creates either a correlation-ghost forerunner or a tail at both positive and negative correlation times if the harmonically distorted sweep is used as the correlation operator. Seriff and Kim conclude that the correlation of the seismic trace with the harmonically distorted sweep is not desirable if the aim is the elimination of the correlation-ghost (sweeps) in the correlated

trace. Li also noted that the baseplate signal, which is part of the groundforce, may in fact be a better correlator than the pilot sweep, because it represents the actual signal propagating into the earth citing Baeten and Ziolkowski, 1990, and that numerous methods to eliminate the harmonic distortion have been investigated during the last thirty years.

Another prior art method known as the pure phase shift filter (PPSF) method exploits the definition of a linear sweep and is implemented as a modification of known correlation processes. It is applied to synthetic and real data for practical results, and due to its mathematical background, is restricted to seismic data generated by upsweeps. Another common method, the variphase sweep method, attempts to eliminate the harmonic distortion of downsweeps. However, it is used to reduce harmonic distortion only with limited success, largely because it is difficult to implement and control with respect to quality (Martin, 1993).

In certain prior art systems, the correlation of a recorded seismogram with a groundforce signal (which includes harmonic distortions and inaccuracies in the feedback system of the vibrator), is based on a conventional convolution model. After the correlation, the seismogram resembles a shot seismogram, but with correlation-ghost noise (non-linear). The PPSF method eliminates the harmonic distortions in the groundforce signal before such a signal is used as the correlator. Provided that the convolution model is true and the groundforce signal is the signal which is propagating from the vibrator into the earth, correlation-ghost noise is eliminated by using deterministic deconvolution instead of carrying out a conventional correlation, which does not require the PPSF. The seismogram is deconvolved with the groundforce signal in the given sweep frequency range.

In one such method the deconvolution (refining) process is applied to uncorrelated seismic data. The convolution consists of the harmonically distorted sweep or one of its modifications, the response of the earth, and the stratigraphic filter. In one aspect

the deconvolution procedure, as is usually done with the correlation procedure, is carried out in the frequency domain and only in the desired frequency range of the input sweep.

There has long been a need for an effective and efficient seismic data pre-processing method. There has been a need, recognized and addressed by the inventors of the present invention, for such a method that does not need to employ spiking deconvolution techniques. There has been a need, recognized and addressed by the present inventors, for a method in which the effects of the presence of random noise are reduced or eliminated.

SUMMARY OF THE PRESENT INVENTION

The present invention discloses, in certain embodiments, a seismic data method for recording and processing vibratory source seismic data, the method including: applying with a vibratory source system a groundforce signal into earth at a selected location, the groundforce signal having a temporal duration and including a reference sweep signal and non-linear noise; recording the groundforce signal with recording apparatus; generating a filter for converting a time derivative of the groundforce signal to a desired short-duration wavelet which, in one aspect, has a temporal duration less than the temporal duration of the groundforce signal; recording at least one reflection signal from a location within the earth of said groundforce signal; and applying the filter to the at least one reflection signal to refine seismic data represented by the at least one reflection signal, thereby producing refined seismic data about the location within the earth.

The present invention also discloses, in certain embodiments a method for making a data shaping filter that employs a short duration wavelet with a bandwidth greater than that of a reference sweep signal included in a groundforce signal. In one aspect such a method is a method for making a shaping filter for improving

seismic data in a reflected signal from the earth, the reflected signal including the reflection of a noise-containing groundforce signal generated by a vibratory source system, the groundforce signal including a reference sweep signal and non-linear noise, and having a temporal duration, the method including producing a short-duration wavelet with a temporal duration less than that of the reference sweep signal; and generating the filter by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

The present invention discloses, in certain embodiments a new seismic data method which employs an actual groundforce signal rather than some other related signal, e.g. an accelerometer signal. Vibrator electronics of a seismic vibratory system having a baseplate and a reaction mass generate an ideal known reference sweep (also "fundamental" or "pilot") sweep signal, and a resulting actual groundforce signal is either computed using known techniques (including known techniques using known accelerometer systems) or is directly measured using an appropriate commercially available force plate system such as that manufactured and sold by geoMagic, Plano, Texas. This computed or directly measured groundforce signal is recorded along with the normal seismic reflection signals, e.g. with a surface geophone spread or other known sensors. A shaping filter (in one aspcet in the frequency domain) is created, according to the present invention, to compress the measured groundforce signal creating a defined short-duration wavelet. The shaping filter is, in one aspect, in the "frequency domain" because this method employs a true representation of the time derivative of groundforce in terms of frequency. Groundforce is directly proportional to particle displacement including far field particle displacement (except for a time delay); the time derivative of displacement is velocity — and velocity of displacement is what is measured by one or more geophones. The vibratory source system may be located on land, on the earth

surface below water, or in water above but not in contact with earth below the system. In one aspect a filter is computed that converts the time derivative of the recorded groundforce signal into a desired, short-duration wavelet signal as follows:

$$F(\omega)=\frac{W(\omega)}{i\omega G_F}$$

where:

$W(\omega)$ = Fourier transform of the desired, short-duration wavelet

$G_F(\omega)$ = Fourier transform of the recorded force signal output of the vibrator

$F(\omega)$ = Fourier transform of the filter

$i=\sqrt{-1};\quad \omega=2\pi f$

Frequency (f) is expressed in cycles per second. The seismic reflection signals are not crosscorrelated with the pilot sweep signal. Instead, the filter is applied to each trace recorded from the surface geophone spread that was generated by that vibrator sweep. By filtering out the groundforce signal (in the form of the created short-duration wavelet) from each reflected earth signal, a refined isolated earth reflectivity signal is obtained, i.e., seismic data uncontaminated with a noisy groundforce signal.

Using this method, the components of the vibrator's output signal (fundamental sweep, non-linear noise — harmonics and subharmonics) are constructively compressed into the desired wavelet, and the harmonic correlation noise is eliminated. Greater stability is achieved in the short-duration wavelet representing each reflection in the recorded data because shotpoint-to-shotpoint variations in topsoil non-linearity are removed from the data as are the noise effects related to non-linearities resulting from the operation of the electrohydraulic vibrator system. Thus, methods according to the present invention constructively use the harmonics and subharmonics of a groundforce signal that includes such

harmonics and subharmonics as, what has been considered to be in the past, undesirable distortions of the signal. These harmonics and subharmonics (the non-linear noise) represent energy that may be used, along with the energy of the main signal, to produce a relatively energetic compressed short-duration wavelet based on which a useful shaping filter may be created for application to raw seismic data. In one aspect such application yields improved data which is more accurate than data produced by known methods such as the method of U.S. Patent 5,550,786 and the method of Li, mentioned above. For example, a known computed and/or ideal groundforce signal may include frequencies ranging from 10 to 120 Hertz; but subharmonics related to the 10 Hz part may be at a 5 Hz frequency and resulting harmonics may be at ~~15~~ 20 Hz and 30 Hz. Certain prior art methods either ignore or seek to negate the effects of such non-linear noise. According to the present invention these subharmonics and harmonics are compressed, along with the ideal non-noise portion of the groundforce signal, to form the desired wavelet. Such wavelet formation itself may be done via known wavelet formation methods; but the present inventors are unaware of the creation of such a wavelet using frequencies outside the spectrum of the main signal for the refinement of vibratory source seismic data.

The desired wavelet may be (but is not limited to) a Klauder wavelet or a minimum phase wavelet.

It is, therefore, an object of at least certain preferred embodiments of the present invention to provide:

New, useful, unique, efficient, nonobvious systems and methods for acquiring and processing seismic data from vibratory sources;

Such systems and methods in which the effects of non-linear noise on seismic data are eliminated, including negating the effects of harmonics and subharmonics of a groundforce ("sweep") signal;

Such systems and methods in which a recorded groundforce (including non-linear noise therein) signal is converted into a

desired compressed short-duration wavelet signal;

Such systems and methods in which such a short-duration wavelet signal has relatively greater stability, and is, in certain aspects, a typical Klauder wavelet or a minimum phase wavelet; and

Such a system in which a created frequency-domain shaping filter is applied to earth reflected seismic data to eliminate the effects of non-linear noise from a vibrator system, producing refined and highly accurate earth reflected seismic data.

The collapsed short-duration wavelet $W(\omega)$ is produced not by doing a correlation, a known mathematical procedure; but by creating a filter which converts each representation of an actual groundforce signal in recorded seismic data to a desired short-duration wavelet and by then applying the filter to the seismic data.

Certain embodiments of this invention are not limited to any particular individual feature disclosed here, but include combinations of them distinguished from the prior art in their structures and functions. Features of the invention have been broadly described so that the detailed descriptions that follow may be better understood, and in order that the contributions of this invention to the arts may be better appreciated. There are, of course, additional aspects of the invention described below and which may be included in the subject matter of the claims to this invention. Those skilled in the art who have the benefit of this invention, its teachings, and suggestions will appreciate that the conceptions of this disclosure may be used as a creative basis for designing other structures, methods and systems for carrying out and practicing the present invention. The claims of this invention are to be read to include any legally equivalent devices or methods which do not depart from the spirit and scope of the present invention.

The present invention recognizes and addresses the previously-mentioned problems and long-felt needs and provides a solution to

those problems and a satisfactory meeting of those needs in its various possible embodiments and equivalents thereof. To one skilled in this art who has the benefits of this invention's realizations, teachings, disclosures, and suggestions, other purposes and advantages will be appreciated from the following description of preferred embodiments, given for the purpose of disclosure, when taken in conjunction with the accompanying drawings. The detail in these descriptions is not intended to thwart this patent's object to claim this invention no matter how others may later disguise it by variations in form or additions of further improvements.

DESCRIPTION OF THE DRAWINGS

A more particular description of embodiments of the invention briefly summarized above may be had by references to the embodiments which are shown in the drawings which form a part of this specification. These drawings illustrate certain preferred embodiments and are not to be used to improperly limit the scope of the invention which may have other equally effective or legally equivalent embodiments.

Fig. 1 is a schematic view of typical vibratory seismic data acquisition and processing system.

Fig. 2 is a schematic view of a system and method according to the present invention.

Fig. 3 is a graphical representation of an undistorted groundforce signal (i.e. without non-linear noise in the signal).

Fig. 4 is a graphical representation of a distorted groundforce signal (i.e. containing non-linear harmonic distortion or noise).

Fig. 5 is a graphical representation of the effect of a prior art correlation method as applied to the undistorted groundforce signal of Fig. 3.

Fig. 6 is a graphical representation of the effect of a prior

art correlation method as applied to the distorted groundforce signal of Fig. 3.

Fig. 7 is a graphical representation of the effect of applying a shaping filter according to the methods of the present invention to the distorted groundforce signal of Fig. 3.

Fig. 8 is a graphical representation of the effect of applying a shaping filter according to the methods of the present invention to a distorted groundforce signal.

DESCRIPTION OF EMBODIMENTS PREFERRED AT THE TIME OF FILING FOR THIS PATENT

The system of Fig. 1 has a vibrator 36 with signal measuring apparatus 38 that measure the actual groundforce signal that is generated into the earth, both located on a truck 40.

The signal that is generated into the earth by vibrator 36 is reflected off the interface between subsurface impedance Im_1 and Im_2 at points I_1, I_2, I_3, and I_4. This reflected signal is detected by geophones D_1, D_2, D_3, and D_4, respectively. The signals generated by vibrator 36 on truck 40 are transmitted to recorder 46 for transfer to tape 48 for combination with raw seismic data received from geophones D_1, D_2, D_3, and D_4. The signals are then transmitted via radio link 42 to a master vibrator memory 44 where they are checked to determine their reliability and are stored for comparison at a later time. The received data signals and the raw seismic data stored on a tape 48 can be transferred to computers at other locations.

Methods of the present invention process this raw data and refine it, eliminating groundforce signal harmonic distortion effects. The measured signal are representative of the actual signals that are generated into the surface of the earth through the vibratory source. These measured signals are minimum phase relatives of the actual signals that are generated into the surface of the earth by this technique.

Fig. 2 shows a system 100 according to the present invention with a vibratory baseplate 102; a support post 104; a vibrating piston system (electrohydraulic) 106; a control valve 110 for the system 104; a reaction mass 112; a baseplate groundforce signal measuring system 108 connected to the baseplate 102; a reaction mass signal measuring system 114 connected to the reaction mass 122; a communication line 116 connecting the system 114 to a computer 120; a communication line 118 connecting the system 108 to the computer 120; and a communication line 122 connecting the computer 120 to another computer 124.

The system 108 may be any known accelerometer system used to measure, record and transmit an accelerometer signal from a baseplate. The system 114, similarly, may be any known accelerometer system used to measure a reaction mass acceleration. The signal that hits the soil is a combination of the reaction mass signal and the signal from the baseplate.

The computer 120 may be any known computer system suitable for receiving the signal(s) transmitted by the systems 108, 114 and for processing them as indicated schematically in Fig. 2 and as described herein, with appropriate storage, memory, computing and processing components therein. The computer 120 may be located at the site of the system 100 or remote therefrom and may, in one aspect, be on a truck (e.g. a truck 40 as in Fig. 1). Similarly, the computer 124 may be any known computer system suitable for applying the created shaping filter to one or more actual recorded seismic data traces. In one particular aspect, a single computer system is a combination of the computers 120 and 124. The computer 124 may be located at the site of the system 100 or remote therefrom. Any known data link system or communication system, including but not limited to wire, wireless, and satellite, may be used to link the system 100 and the computers 120, 124.

Fig. 2 shows steps A – C for generating the desired shaping filter $F(\omega)$. In step D, this filter is applied to actual seismic

data to produce processed, refined data T from which the effects of non-linear noise of the groundforce signal has been eliminated.

In Step A the computer produces a representation of the groundforce signal (which includes a reference or pilot sweep signal and harmonic distortions due to non-linearities discussed above) in terms of time, $G_F(t)$. This is either simply a measured signal representation (e.g. directly from a force measuring device) which is processed by the computer 120 to yield $G_F(t)$ or a computed signal computed from outputs from the accelerometers.

In Step B a mathematical representation $W(\omega)$ of a desired wavelet is produced, in one aspect a zero or minimum phase wavelet with a bandwidth equal to or greater than that of the reference (pilot) sweep signal. This is a desired ideal signal representative of the groundforce signal, a wavelet in which the energy of non-linear noise has been used and the effects of the noise then eliminated by converting it to useful seismic energy.

In Step C, using the desired wavelet $W(\omega)$ and the time derivative of the groundforce signal $G_F(t)$, a shaping filter $F(\omega)$ is produced. The shaping filter can be produced by any known method, including but not limited to, dividing the Fourier transform of the desired short-duration wavelet by the Fourier transform of the time derivative of the actual groundforce signal.

In Step D, the shaping filter $F(\omega)$ is applied by known methods (e.g. but not limited to either in the time domain or the frequency domain), to actual seismic data trace recorded data produced by the signal represented by $G_F(t)$ to produce the processed data T.

In one aspect of the present invention, the shaping filter is expressed and used as $F(\omega)$ (Step C, above), a Fourier transform of the filter. The short-duration wavelet is used as $W(\omega)$ (Step B, above), a Fourier transform of the wavelet and the groundforce is used as $G_F(\omega)$, a Fourier transform of the mathematical representation of the groundforce signal (Step A) above.

For this particular embodiment of the invention, the

following notation will be used:

G_F groundforce
G_M measured groundforce
D measured seismic data
R_E earth reflectivity sequence
W desired wavelet
M_E earth filter (e.g. a Q-filter)

In one aspect groundforce is measured in newtons; the seismic data are voltage traces representative of velocity in meters per second, and $F(\omega)$, M_E, $W(\omega)$, and R_E are dimensionless numerical mathematical constructs. The groundforce signal $G_F(t)$is taken as the representation of the radiated groundforce signal. (Alternatively as mentioned above, base plate and reaction mass acceleration could be used instead to produce a computed groundforce signal.) Therefore, in the frequency domain the filter equation is, where $F(\omega)$ is the shaping filter (a "dot" over the ground force symbol in terms of frequency indicates the time derivative thereof):

$$\dot{G}_F(\omega)\cdot F(\omega)=W(\omega)\Rightarrow F(\omega)=\frac{W(\omega)}{\dot{G}_F(\omega)}$$

The next step is the application of the filter to the raw seismic data $D(\omega)$; $D_C(\omega)$ is the refined data in the frequency domain:

$$D_C(\omega)=F(\omega)\cdot D(\omega)=\frac{W(\omega)}{\dot{G}_F(\omega)}\cdot D(\omega)$$

where the raw seismic data is defined as:

$$D(\omega)=\dot{G}_F(\omega)\cdot R_E(\omega)\cdot M_E(\omega)$$

Therefore the data (T in Fig. 2) after processing are:

$$\frac{W(\omega)}{G_F^{\bullet}(\omega)} \cdot G_F^{\bullet}(\omega) \cdot R_E(\omega) \cdot M_E(\omega) =$$

$$R_E(\omega) \cdot M_E(\omega) \cdot W(\omega) = D_C(\omega) = T$$

As illustrated in Figs. 3 - 7, use of a known correlation method does not eliminate the effects of non-linear noise from a signal (see Fig. 6) and use of a shaping filter according to the present invention does accomplish this (see Fig. 7). Fig. 7 shows a short duration wavelet according to the present invention that has substantially the same bandwidth as that of the signal of Fig. 3. If the signal of Fig. 3 had a greater bandwidth, then the short duration wavelet would have a bandwidth greater than that of the signal of Fig. 3. It is within the scope of this invention to produce a desired short duration wavelet (as in Fig. 8) with a bandwidth greater than that of a reference sweep signal in a groundforce signal from a vibratory source system. In Figs. 3 - 7, the horizontal axis is a time axis with time increasing from left to right and the vertical axis is an amplitude axis (e.g. measured voltages) with amplitude increasing from bottom to top.

In conclusion, therefore, it is seen that the present invention and the embodiments disclosed herein and those covered by the appended claims are well adapted to carry out the objectives and obtain the ends set forth. Certain changes can be made in the subject matter without departing from the spirit and the scope of this invention. It is realized that changes are possible within the scope of this invention and it is further intended that each element or step recited in any of the following claims is to be understood as referring to all equivalent elements or steps. The following claims are intended to cover the invention as broadly as legally possible in whatever form it may be utilized. The invention claimed herein is new and novel in accordance with 35 U.S.C. § 102 and satisfies the conditions for patentability in § 102. The invention claimed herein is not obvious in accordance with 35

U.S.C. § 103 and satisfies the conditions for patentability in § 103. This specification and the claims that follow are in accordance with all of the requirements of 35 U.S.C. § 112.

Therefore, the present invention, in certain aspects, discloses a seismic data method for recording and processing vibratory source seismic data, the method including applying with a vibratory source system a groundforce signal into earth at a selected location, said groundforce signal including a reference sweep signal and non-linear noise, said reference signal having a temporal duration, recording with first recording apparatus said groundforce signal, generating a filter for converting a time derivative of said groundforce signal to a short-duration wavelet, recording with second recording apparatus at least one reflection signal from a location within the earth of said groundforce signal, and applying said filter to said at least one reflection signal to refine seismic data represented by said at least one reflection signal producing refined seismic data about the location within the earth; such a seismic data method wherein the short duration wavelet has a temporal duration less than the temporal duration of the reference sweep signal; such a seismic data method wherein the vibratory source system contacts soil and the seismic data method including driving the vibratory source system with sufficient peak force so that creation of non-linear noise in the groundforce signal due to non-linearity of the soil and non-linearity in the vibratory source system is enhanced; such a seismic data method wherein the reference sweep signal has a bandwidth and the filter has a bandwidth greater than that of the reference sweep signal; such a seismic data method wherein the refined seismic data is an improved compressed seismic reflection trace representative of the location within the earth; such a seismic data method wherein the at least one reflection signal is a plurality of reflection signals, each reflecting from a different location within the earth back to the recording apparatus and the method including recording with the recording apparatus the plurality of reflection signals,

and applying said filter to each of the plurality of reflection signals; such a seismic data method wherein the at least one reflection signal is a plurality of reflection signals, each reflecting from a different location within the earth back to the recording apparatus, the recording apparatus including a plurality of spaced-apart recording devices each of which receives and records at least one of the plurality of reflection signals, and the method including recording with the recording apparatus the plurality of reflection signals, and applying said filter to each of the plurality of reflection signals; such a seismic data method wherein the vibratory source system is at earth surface and the second recording apparatus is at earth surface spaced-apart from the vibratory source system; such a seismic data system wherein the short-duration wavelet has a bandwidth greater than a bandwidth of the reference sweep signal; such a seismic data method wherein the short-duration wavelet is produced by a method from the group consisting of autocorrelation of the reference sweep signal and a method including designing a zero or minimum phase wavelet with a prescribed amplitude spectrum; such a seismic data method wherein the short-duration wavelet is a Klauder wavelet or a minimum phase wavelet; such a seismic data method wherein the filter is generated by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal; such a seismic data method wherein the filter is applied to the at least one reflection signal by a circular convolution method; such a seismic data method wherein particles at the location within the earth are moved by the groundforce signal, the particles then having a velocity, and the ground force signal reflecting from an earth layer beneath earth surface producing the at least one reflection signal indicative of reflectivity of earth at that earth layer and wherein the second recording apparatus includes transducer apparatus for sensing velocity of soil particles adjacent the second recording apparatus and the soil particles moved by the at least one reflection signal, and the method

including translating with computing apparatus the at least one reflection signal into the seismic data to which the filter is applied; such a seismic data method wherein the groundforce signal is measured directly with a force measuring device at the vibratory source system; such a seismic data method wherein the vibratory source system includes a reaction mass with an interconnected accelerometer and a baseplate with an interconnected accelerometer and a groundforce signal representation is computed from outputs from the accelerometers; such a seismic data method wherein the non-linear noise includes harmonic distortion due to non-linearity in the vibratory source system and in contact of the vibratory source system and the soil; such a seismic data method wherein the first recording apparatus is adjacent the vibratory source system; such a seismic data method wherein the second recording apparatus is adjacent the vibratory source system; such a seismic data method wherein the first and second recording apparatus are adjacent the vibratory source system; such a seismic data method wherein the first and second recording apparatus are remote from the vibratory source system and the method including transmitting with first transmitting apparatus a signal representative of the groundforce signal to the first recording apparatus, and transmitting with second transmitting apparatus a signal representative of the at least one reflection signal to the second recording apparatus; such a seismic data method wherein a computer is interconnected with the vibratory source system and with the first and second recording apparatus and the computer computes the short-duration wavelet and generates the filter; such a seismic data method wherein the computer applies the filter to the at least one reflection signal; such a seismic data method wherein the computer is adjacent the vibratory source system; such a seismic data method wherein the computer is remote from the vibratory source system; such a seismic data method wherein the first and second recording apparatus are a single recording apparatus; and such a seismic data method wherein the first and second transmitting apparatus are a single

transmitting apparatus in intercommunication with both the vibratory source system and the recording apparatuses.

The present invention discloses, in certain aspects, a method for making a shaping filter for improving seismic data, the seismic data comprising a reflected signal from earth, the reflected signal comprising the reflection of a noise-containing groundforce signal generated by a vibratory source system, the groundforce signal including a reference sweep signal and non-linear noise, the reference sweep signal having a temporal duration, the method including producing a short-duration wavelet with a temporal duration less than that of the reference sweep signal, and generating the filter by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

The present invention discloses, in certain aspects, a method for making a shaping filter for improving seismic data, the seismic data comprising a reflected signal from earth, the reflected signal comprising the reflection of a noise-containing groundforce signal generated by a vibratory source system, the groundforce signal including a reference sweep signal and non-linear noise, the reference sweep signal having a bandwidth duration, the method including producing a short-duration wavelet with a bandwidth greater than that of the reference sweep signal, and generating the filter by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

What is claimed is:

CLAIMS:

1. A seismic data method for recording and processing vibratory source seismic data, the method comprising

applying with a vibratory source system a groundforce signal into earth at a selected location, said groundforce signal including a reference sweep signal and non-linear noise, said reference signal having a temporal duration,

recording with first recording apparatus said groundforce signal,

generating a filter for converting a time derivative of said groundforce signal to a short-duration wavelet,

recording with second recording apparatus at least one reflection signal from a location within the earth of said groundforce signal, and

applying said filter to said at least one reflection signal to refine seismic data represented by said at least one reflection signal producing refined seismic data about the location within the earth.

2. The seismic data method of claim 1 wherein the short duration wavelet has a temporal duration less than the temporal duration of the reference sweep signal.

3. The seismic data method of claim 1 wherein the vibratory source system contacts soil and the seismic data method further comprising

driving the vibratory source system with sufficient peak force so that creation of non-linear noise in the groundforce signal due to non-linearity of the soil and non-linearity in the vibratory source system is enhanced.

4. A seismic data method of claim 1 wherein the reference sweep signal has a bandwidth and the filter has a bandwidth greater than that of the reference sweep signal.

5. The seismic data method of claim 1 wherein the refined seismic data is an improved compressed seismic reflection trace

representative of the location within the earth.

6. The seismic data method of claim 1 wherein

the at least one reflection signal is a plurality of reflection signals, each reflecting from a different location within the earth back to the recording apparatus and the method further comprising

recording with the recording apparatus the plurality of reflection signals, and

applying said filter to each of the plurality of reflection signals.

7. The seismic data method of claim 1 wherein

the at least one reflection signal is a plurality of reflection signals, each reflecting from a different location within the earth back to the recording apparatus, the recording apparatus including a plurality of spaced-apart recording devices each of which receives and records at least one of the plurality of reflection signals, and the method further comprising

recording with the recording apparatus the plurality of reflection signals, and

applying said filter to each of the plurality of reflection signals.

8. The seismic data method of claim 1 wherein the vibratory source system is at earth surface and the second recording apparatus is at earth surface spaced-apart from the vibratory source system.

9. The seismic data system of claim 1 wherein the short-duration wavelet has a bandwidth greater than a bandwidth of the reference sweep signal.

10. The seismic data method of claim 1 wherein the short-duration wavelet is produced by a method from the group consisting of autocorrelation of the reference sweep signal and a method including designing a zero or minimum phase wavelet with a prescribed amplitude spectrum.

11. The seismic data method of claim 10 wherein the short-duration wavelet is a Klauder wavelet.

12. The seismic data method of claim 10 wherein the short-duration wavelet is a minimum phase wavelet.

13. The seismic data method of claim 1 wherein the filter is generated by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

14. The seismic data method of claim 1 wherein the filter is applied to the at least one reflection signal by a circular convolution method.

15. The seismic data method of claim 1 wherein particles at the location within the earth are moved by the groundforce signal, the particles then having a velocity, and the ground force signal reflecting from an earth layer beneath earth surface producing the at least one reflection signal indicative of reflectivity of earth at that earth layer and wherein the second recording apparatus includes transducer apparatus for sensing velocity of soil particles adjacent the second recording apparatus and the soil particles moved by the at least one reflection signal, and the method further comprising

translating with computing apparatus the at least one reflection signal into the seismic data to which the filter is applied.

16. The seismic data method of claim 1 wherein the groundforce signal is measured directly with a force measuring device at the vibratory source system.

17. The seismic data method of claim 1 wherein the vibratory source system includes a reaction mass with an interconnected accelerometer and a baseplate with an interconnected accelerometer and a groundforce signal representation is computed from outputs from the accelerometers.

18. The seismic data method of claim 1 wherein the non-linear noise includes harmonic distortion due to non-linearity in the

vibratory source system and in contact of the vibratory source system and the soil.

19. The seismic data method of claim 1 wherein the first recording apparatus is adjacent the vibratory source system.

20. The seismic data method of claim 1 wherein the second recording apparatus is adjacent the vibratory source system.

21. The seismic data method of claim 1 wherein the first and second recording apparatus are adjacent the vibratory source system.

22. The seismic data method of claim 1 wherein the first and second recording apparatus are remote from the vibratory source system and the method further comprising

transmitting with first transmitting apparatus a signal representative of the groundforce signal to the first recording apparatus, and

transmitting with second transmitting apparatus a signal representative of the at least one reflection signal to the second recording apparatus.

23. The seismic data method of claim 1 wherein a computer is interconnected with the vibratory source system and with the first and second recording apparatus and the computer computes the short-duration wavelet and generates the filter.

24. The seismic data method of claim 23 wherein the computer applies the filter to the at least one reflection signal.

25. The seismic data method of claim 23 wherein the computer is adjacent the vibratory source system.

26. The seismic data method of claim 23 wherein the computer is remote from the vibratory source system.

27. The seismic data method of claim 1 wherein the first and second recording apparatus are a single recording apparatus.

28. The seismic data method of claim 22 wherein the first and second transmitting apparatus are a single transmitting apparatus in intercommunication with both the vibratory source system and the recording apparatuses.

29. A seismic data method for recording and processing vibratory source seismic data, the method comprising

applying with a vibratory source system a groundforce signal into earth at a selected location, said groundforce signal including a reference sweep signal and non-linear noise, said reference signal having a temporal duration,

recording with first recording apparatus said groundforce signal,

generating a filter for converting a time derivative of said groundforce signal to a short-duration wavelet,

recording with second recording apparatus at least one reflection signal from a location within the earth of said groundforce signal,

applying said filter to said at least one reflection signal to refine seismic data represented by said at least one reflection signal producing refined seismic data about the location within the earth,

wherein $F(\omega)$ is a function of the filter and

$$F(\omega) = \frac{W(\omega)}{\dot{G}_F(\omega)}$$

where

$F(\omega)$ = Fourier transform of the filter

$W(\omega)$ = Fourier transform of the wavelet

$G_F(\omega)$ = Fourier transform of the groundforce signal

the filter applied to the seismic data, $D(\omega)$, as $F(\omega) \cdot D(\omega)$

where

$$D(\omega) = \dot{G}_F(\omega) \cdot R_E(\omega) \cdot M_E(\omega)$$

where

G_F groundforce

G_M measured groundforce

D measured seismic data

R_E earth reflectivity sequence

W desired wavelet

M_E earth filter (e.g. a Q-filter)

and the refined seismic data is T:

$$\frac{W(\omega)}{G_F^{\bullet}(\omega)} \cdot G_F^{\bullet}(\omega) \cdot R_E(\omega) \cdot M_E(\omega) =$$

$$R_E(\omega) \cdot M_E(\omega) \cdot W(\omega) = D_C(\omega) = T$$

30. A method for making a shaping filter for improving seismic data, the seismic data comprising a reflected signal from earth, the reflected signal comprising the reflection of a noise-containing groundforce signal generated by a vibratory source system, the groundforce signal including a reference sweep signal and non-linear noise, the reference sweep signal having a temporal duration, the method comprising

producing a short-duration wavelet with a temporal duration less than that of the reference sweep signal, and

generating the filter by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

31. The method of claim 30 wherein $F(\omega)$ is a function of the filter and the filter is computed as

$$F(\omega) = \frac{W(\omega)}{i\omega G_F}$$

where:

$W(\omega)$ = Fourier transform of the desired, short-duration wavelet

$G_F(\omega)$ = Fourier transform of the recorded force signal output of the vibrator

$F(\omega)$ = Fourier transform of the filter

$i = \sqrt{-1}; \quad \omega = 2\pi f$

32. A method for making a shaping filter for improving seismic data, the seismic data comprising a reflected signal from earth, the reflected signal comprising the reflection of a noise-containing groundforce signal generated by a vibratory source system, the groundforce signal including a reference sweep signal and non-linear noise, the reference sweep signal having a bandwidth duration, the method comprising

producing a short-duration wavelet with a bandwidth greater than that of the reference sweep signal, and

generating the filter by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

33. The method of claim 32 wherein $F(\omega)$ is a function of the filter and the filter is computed as

$$F(\omega) = \frac{W(\omega)}{i\omega G_F}$$

where:

$W(\omega)$ = Fourier transform of the desired, short-duration wavelet

$G_F(\omega)$ = Fourier transform of the recorded force signal output of the vibrator

$F(\omega)$ = Fourier transform of the filter

$i = \sqrt{-1}; \quad \omega = 2\pi f$

IN THE UNITED STATES PATENT
AND TRADEMARK OFFICE

APPLICATION FOR
UNITED STATES UTILITY PATENT

SEISMIC DATA ACQUISITION AND PROCESSING USING NON-LINEAR DISTORTION IN A GROUNDFORCE SIGNAL

Extra set claims (1 - 33) for PTO Examiner

INVENTORS
FREDERICK J. BARR
JOSEF PAFFENHOLZ

CLAIMS:

1. A seismic data method for recording and processing vibratory source seismic data, the method comprising

applying with a vibratory source system a groundforce signal into earth at a selected location, said groundforce signal including a reference sweep signal and non-linear noise, said reference signal having a temporal duration,

recording with first recording apparatus said groundforce signal,

generating a filter for converting a time derivative of said groundforce signal to a short-duration wavelet,

recording with second recording apparatus at least one reflection signal from a location within the earth of said groundforce signal, and

applying said filter to said at least one reflection signal to refine seismic data represented by said at least one reflection signal producing refined seismic data about the location within the earth.

2. The seismic data method of claim 1 wherein the short duration wavelet has a temporal duration less than the temporal duration of the reference sweep signal.

3. The seismic data method of claim 1 wherein the vibratory source system contacts soil and the seismic data method further comprising

driving the vibratory source system with sufficient peak force so that creation of non-linear noise in the groundforce signal due to non-linearity of the soil and non-linearity in the vibratory source system is enhanced.

4. A seismic data method of claim 1 wherein the reference sweep signal has a bandwidth and the filter has a bandwidth greater than that of the reference sweep signal.

5. The seismic data method of claim 1 wherein the refined seismic data is an improved compressed seismic reflection trace

representative of the location within the earth.

6. The seismic data method of claim 1 wherein

the at least one reflection signal is a plurality of reflection signals, each reflecting from a different location within the earth back to the recording apparatus and the method further comprising

recording with the recording apparatus the plurality of reflection signals, and

applying said filter to each of the plurality of reflection signals.

7. The seismic data method of claim 1 wherein

the at least one reflection signal is a plurality of reflection signals, each reflecting from a different location within the earth back to the recording apparatus, the recording apparatus including a plurality of spaced-apart recording devices each of which receives and records at least one of the plurality of reflection signals, and the method further comprising

recording with the recording apparatus the plurality of reflection signals, and

applying said filter to each of the plurality of reflection signals.

8. The seismic data method of claim 1 wherein the vibratory source system is at earth surface and the second recording apparatus is at earth surface spaced-apart from the vibratory source system.

9. The seismic data system of claim 1 wherein the short-duration wavelet has a bandwidth greater than a bandwidth of the reference sweep signal.

10. The seismic data method of claim 1 wherein the short-duration wavelet is produced by a method from the group consisting of autocorrelation of the reference sweep signal and a method including designing a zero or minimum phase wavelet with a prescribed amplitude spectrum.

11. The seismic data method of claim 10 wherein the short-duration wavelet is a Klauder wavelet.

12. The seismic data method of claim 10 wherein the short-duration wavelet is a minimum phase wavelet.

13. The seismic data method of claim 1 wherein the filter is generated by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

14. The seismic data method of claim 1 wherein the filter is applied to the at least one reflection signal by a circular convolution method.

15. The seismic data method of claim 1 wherein particles at the location within the earth are moved by the groundforce signal, the particles then having a velocity, and the ground force signal reflecting from an earth layer beneath earth surface producing the at least one reflection signal indicative of reflectivity of earth at that earth layer and wherein the second recording apparatus includes transducer apparatus for sensing velocity of soil particles adjacent the second recording apparatus and the soil particles moved by the at least one reflection signal, and the method further comprising

translating with computing apparatus the at least one reflection signal into the seismic data to which the filter is applied.

16. The seismic data method of claim 1 wherein the groundforce signal is measured directly with a force measuring device at the vibratory source system.

17. The seismic data method of claim 1 wherein the vibratory source system includes a reaction mass with an interconnected accelerometer and a baseplate with an interconnected accelerometer and a groundforce signal representation is computed from outputs from the accelerometers.

18. The seismic data method of claim 1 wherein the non-linear noise includes harmonic distortion due to non-linearity in the

vibratory source system and in contact of the vibratory source system and the soil.

19. The seismic data method of claim 1 wherein the first recording apparatus is adjacent the vibratory source system.

20. The seismic data method of claim 1 wherein the second recording apparatus is adjacent the vibratory source system.

21. The seismic data method of claim 1 wherein the first and second recording apparatus are adjacent the vibratory source system.

22. The seismic data method of claim 1 wherein the first and second recording apparatus are remote from the vibratory source system and the method further comprising

transmitting with first transmitting apparatus a signal representative of the groundforce signal to the first recording apparatus, and

transmitting with second transmitting apparatus a signal representative of the at least one reflection signal to the second recording apparatus.

23. The seismic data method of claim 1 wherein a computer is interconnected with the vibratory source system and with the first and second recording apparatus and the computer computes the short-duration wavelet and generates the filter.

24. The seismic data method of claim 23 wherein the computer applies the filter to the at least one reflection signal.

25. The seismic data method of claim 23 wherein the computer is adjacent the vibratory source system.

26. The seismic data method of claim 23 wherein the computer is remote from the vibratory source system.

27. The seismic data method of claim 1 wherein the first and second recording apparatus are a single recording apparatus.

28. The seismic data method of claim 22 wherein the first and second transmitting apparatus are a single transmitting apparatus in intercommunication with both the vibratory source system and the recording apparatuses.

29. A seismic data method for recording and processing vibratory source seismic data, the method comprising

applying with a vibratory source system a groundforce signal into earth at a selected location, said groundforce signal including a reference sweep signal and non-linear noise, said reference signal having a temporal duration,

recording with first recording apparatus said groundforce signal,

generating a filter for converting a time derivative of said groundforce signal to a short-duration wavelet,

recording with second recording apparatus at least one reflection signal from a location within the earth of said groundforce signal,

applying said filter to said at least one reflection signal to refine seismic data represented by said at least one reflection signal producing refined seismic data about the location within the earth,

wherein $F(\omega)$ is a function of the filter and

$$F(\omega) = \frac{W(\omega)}{\dot{G}_F(\omega)}$$

where

$F(\omega)$ = Fourier transform of the filter

$W(\omega)$ = Fourier transform of the wavelet

$G_F(\omega)$ = Fourier transform of the groundforce signal

the filter applied to the seismic data, $D(\omega)$, as $F(\omega) \cdot D(\omega)$

where

$$D(\omega) = \dot{G}_F(\omega) \cdot R_E(\omega) \cdot M_E(\omega)$$

where

G_F groundforce

G_M measured groundforce

D measured seismic data

R_E earth reflectivity sequence

W desired wavelet

M_E earth filter (e.g. a Q-filter)

and the refined seismic data is T:

$$\frac{W(\omega)}{G_F^{\bullet}(\omega)} \cdot G_F^{\bullet}(\omega) \cdot R_E(\omega) \cdot M_E(\omega) =$$

$$R_E(\omega) \cdot M_E(\omega) \cdot W(\omega) = D_C(\omega) = T$$

30. A method for making a shaping filter for improving seismic data, the seismic data comprising a reflected signal from earth, the reflected signal comprising the reflection of a noise-containing groundforce signal generated by a vibratory source system, the groundforce signal including a reference sweep signal and non-linear noise, the reference sweep signal having a temporal duration, the method comprising

producing a short-duration wavelet with a temporal duration less than that of the reference sweep signal, and

generating the filter by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

31. The method of claim 30 wherein $F(\omega)$ is a function of the filter and the filter is computed as

$$F(\omega) = \frac{W(\omega)}{i\omega G_F}$$

where:

$W(\omega)$ = Fourier transform of the desired, short-duration wavelet

$G_F(\omega)$ = Fourier transform of the recorded force signal output of the vibrator

$F(\omega)$ = Fourier transform of the filter

$i = \sqrt{-1}; \quad \omega = 2\pi f$

32. A method for making a shaping filter for improving seismic data, the seismic data comprising a reflected signal from earth, the reflected signal comprising the reflection of a noise-containing groundforce signal generated by a vibratory source system, the groundforce signal including a reference sweep signal and non-linear noise, the reference sweep signal having a bandwidth duration, the method comprising

producing a short-duration wavelet with a bandwidth greater than that of the reference sweep signal, and

generating the filter by dividing a Fourier transform of the short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal.

33. The method of claim 32 wherein $F(\omega)$ is a function of the filter and the filter is computed as

$$F(\omega) = \frac{W(\omega)}{i\omega G_F}$$

where:

$W(\omega)$ = Fourier transform of the desired, short-duration wavelet

$G_F(\omega)$ = Fourier transform of the recorded force signal output of the vibrator

$F(\omega)$ = Fourier transform of the filter

$i = \sqrt{-1}; \quad \omega = 2\pi f$

ABSTRACT

The present invention discloses, in certain aspects, a system and method for improving vibratory source seismic data in which a filter is produced which converts a recorded seismic groundforce signal (including harmonic distortion therein) into a desired short-duration wavelet which is used as the basis for generating a filter for application to the seismic data. In one aspect, the present invention provides a seismic data method for recording and processing vibratory source seismic data, the method including applying with a vibratory source system a groundforce signal into earth at a selected location, said groundforce signal having a temporal duration and including a reference sweep signal and non-linear noise, recording with first recording apparatus said groundforce signal, generate a filter for converting a time derivative of said groundforce signal to a short-duration wavelet with a temporal duration less than the temporal duration of the groundforce signal, recording with second recording apparatus at least one reflection signal from a location within the earth of said groundforce signal, and applying said filter to said at least one reflection signal to refine seismic data represented by said at least one reflection signal producing refined seismic data about the location within the earth. A method for making a shaping filter has been invented for improving seismic data by dividing a Fourier transform of a short-duration wavelet by a Fourier transform of a time derivative of the groundforce signal, the short-duration wavelet having a bandwidth greater than that of a reference sweep signal included in the groundforce signal.

DECLARATION and POWER OF ATTORNEY for PATENT APPLICATION
English Language Declaration

As a below named inventor, I hereby declare that:

My residence, post office address and citizenship are as stated below next to my name.

I believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

SEISMIC DATA ACQUISITION AND PROCESSING USING NON-LINEAR DISTORTION IN A GROUNDFORCE SIGNAL

the specification of which
(check one)
✓ is attached hereto.

was filed on ______________________________ as

Application Serial No. ______________________________
and was amended on ______________________________.
(if applicable)

I hereby state that I have reviewed and understand the contents of the above identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the examination of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, §119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate having a filing date before that of the application on which priority is claimed:

Prior Foreign Application(s): **NONE**

			Priority Claimed	
(Number)	(Country)	(Day/Month/Year Filed)	☐ Yes	☐ No
(Number)	(Country)	(Day/Month/Year Filed)	☐ Yes	☐ No
(Number)	(Country)	(Day/Month/Year Filed)	☐ Yes	☐ No

I hereby claim the benefit under Title 35, United States Code, §120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, §112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, §1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application:

(Application Serial No.)	(Filing Date)	(Status: Patented, Pending, Abandoned)
(Application Serial No.)	(Filing Date)	(Status: Patented, Pending, Abandoned)
(Application Serial No.)	(Filing Date)	(Status: Patented, Pending, Abandoned)
(Application Serial No.)	(Filing Date)	(Status: Patented, Pending, Abandoned)

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under Section 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

POWER OF ATTORNEY: As a named inventor, I hereby appoint the following attorney(s) and/or agent(s) to prosecute this application and transact all business in the Patent and Trademark Office connected therewith.

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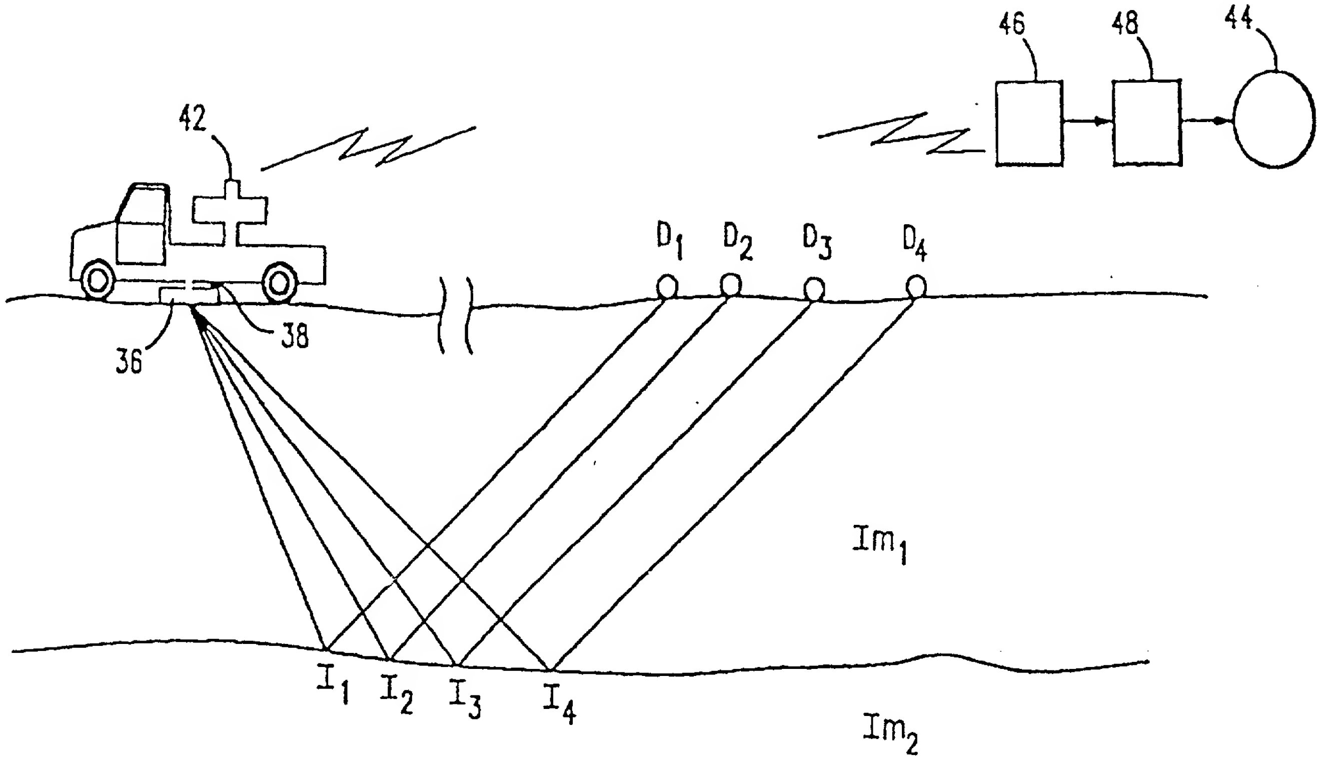
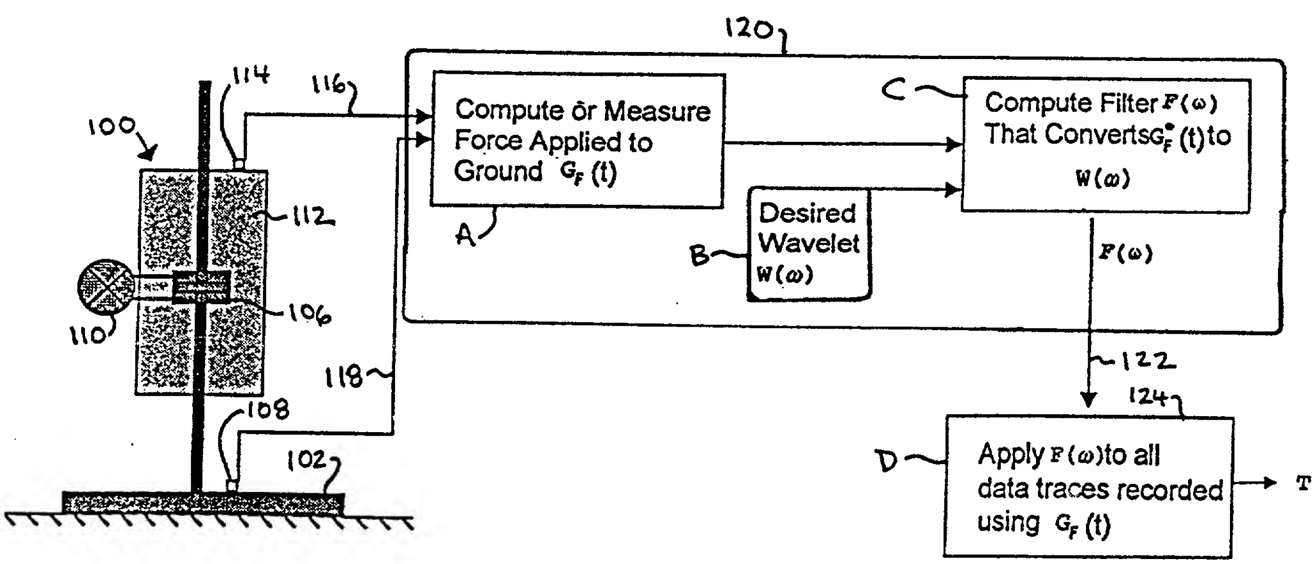


46
48
44
42
D1
D2
D3
D4
36
38
Im1
I1
I2
I3
I4
Im2

Fig. 1



120
114
116
100
Compute or Measure Force Applied to Ground G_F (t)
C
Compute Filter $F(\omega)$ That Converts G_F^* (t) to $W(\omega)$
112
A
Desired Wavelet $W(\omega)$
B
106
110
$F(\omega)$
118
122
124
108
102
D
Apply $F(\omega)$ to all data traces recorded using G_F (t)
T

Fig. 2

Fig. 3

Undistorted ground force (GF)

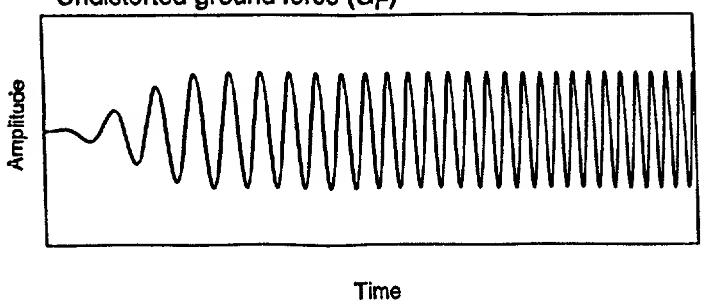


Fig. 4

Distorted ground force (GF)

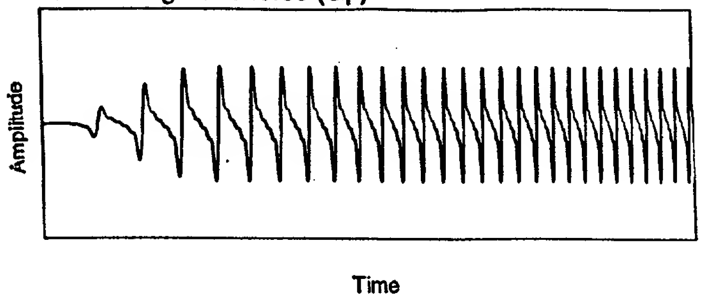


Fig. 5 PRIOR ART

Undistorted ground force (GF) correlated with pilot sweep.

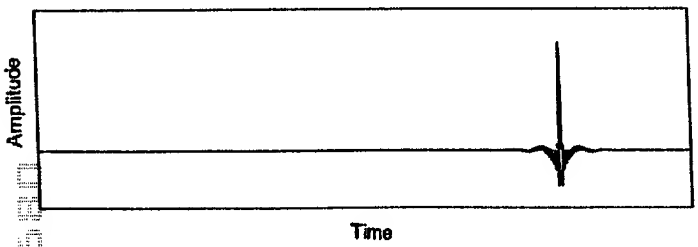
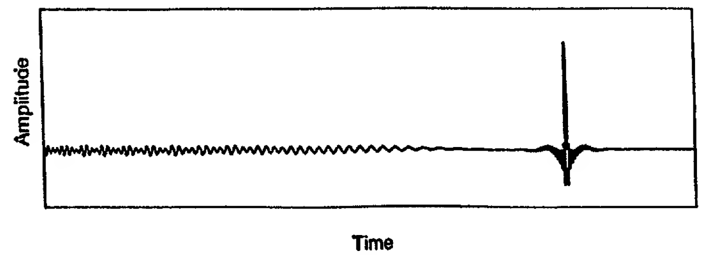


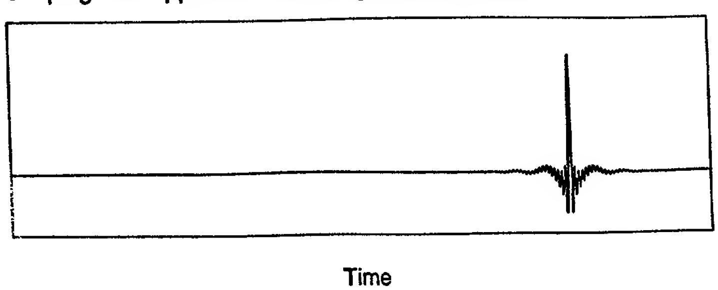
Fig. 6 PRIOR ART

Distorted ground force (GF) correlated with pilot sweep.



Shaping filter applied to distorted ground force (GF).

Fig. 7



Shaping filter applied to distorted ground force (GF).

Fig. 8